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Environmental aspects and challenges of oilseed produced biodiesel in Southeast Asia

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ABSTRACT

Research on alternative fuel for the vehemently growing number of automotivesis intensified due to environmental reasons rather than turmoil in energy price and supply. From the policy and steps to emphasis the use of biofuel by governments all around the world, this can be comprehended that biofuel have placed itself as a number one substitute for fossil fuels. These phenomena made Southeast Asia a prominent exporter of biodiesel. But thrust in biodiesel production from oilseeds of palm and *Jatropha curcas* in Malaysia, Indonesia and Thailand is seriously threatening environmental harmony. This paper focuses on this critical issue of biodiesels environmental impacts, policy, standardization of this region as well as on the emission of biodiesel in automotive uses. To draw a bottom line on feasibilities of different feedstock of biodiesel, a critical analysis on oilseed yield rate, land use, engine emissions and oxidation stability is reviewed. Palm oil based biodiesel is clearly ahead in all these aspects of feasibility, except in the case of NO_x where it lags from conventional petro diesel.

Contents

1. Introduction

Demand of transport fuel is growing rapidly all over the world. Among all automotives, diesel run vehicles are becoming more popular day by day because of its superiority in fuel efficiency [1] and low emission of CO_2, CO, HC [2]. The diesel engine is invented

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by Dr. Rudolph Diesel and run by peanut oil at the Paris Exposition of 1900. So it has been established from then that, high temperature of diesel engine is able to run on variety of vegetable oils [3]. Today diesel-powered vehicles represent about one-third of the vehicles sold in Europe and in the United States it is predicted that diesel run automotives will rise from 4% (2004) to 11% by 2012. Being alternative for petro diesel in transportation sector, biodiesel leads to the easiest and most crucial solution for environmental problems as it does not require any engine modifications and reduces greenhouse gas (GHG) emission substantially as well as improves lubricity. This makes it more adaptable to current energy scenario to ensure energy security, environmental sustainability, and boost rural development by shifting of power from petro to agro-industry, simultaneously.

By using raw vegetable oils as fuel many engine problem evolved like coking of injectors on piston and head of engine, carbon deposits on piston and head of engine, excessive engine wear [4–6]. To compensate this problem, most researchers [5,7,8] have recommended using transesterification of vegetable oils to reduce viscosity. This transesterified vegetable oil is termed as biodiesel. Transesterification is an esterification process of long chained triglycerides of vegetable oils into fatty acid methyl esters (FAME) which is coined as biodiesel. So far, many vegetable oils have been used to produce biodiesel viz. of peanut, rapeseed, safflower, sunflower, soya bean, palm, coconut, corn, cottonseed, linseed. Also some non-edible oils like Mahua, Neem, Karanja and Jatorpha came into lime light after the fuss of food vs. fuel debate worldwide. But this debate lost its ground as most of the government policies permits only 5–20% biodiesel blend (B5–B20) with petro diesel. Biodiesel have proved its technical soundness in low percentage blending by the field trials and experiments carried out by researchers in last decade.

Malaysia and Indonesia are respectively largest and second largest producers of palm oil in the world, jointly they produces 85% of world's palm oil. In Southeast Asia (SE Asia) biodiesel production is drastically rising due to its high potentiality and yield factor of palm. Tropical climate and cheap man power of this region is another beneficial point for growing of this plant [9]. Malaysia's biodiesel production is majorly palm oil based though it has taken some initiative to introduce Jatropha production in mass level. Palm oil is derived from the flesh of the fruit of the oil palm tree *Elais guineensis*. Palm tree is originated in West Africa (more specifically Guinea Coast) [10] and initiated in Malaysia in 1870s as ornamental plant and in Thailand before World War II. In both these countries, first commercial plantation started in 1960s [11]. Indonesia also uses sugarcane and cassava for bioethanol production. Thailand uses molasses, cassava and sugarcane for bioethanol production. Palm is an established biodiesel feedstock in Indonesia and Jatropha is also getting importance for a yield factor of 1.2 tons/ha [12]. As this review article is focused on biodiesel, it will discuss about major biodiesel feedstock of this region only, i.e. palm oil (*E. guineensis*) and *Jatropha curcas* (*J. curcas*) is a large shrub or tree commonly found throughout most of the tropical and sub-tropical regions of the world. *J. curcas* plant is a drought-resistant, perennial plant living up to 50 years and has the capability to grow on marginal soils. It requires very little irrigation and grows in all types of soils. The production of Jatropha seeds is about 0.8 kg/m^2 per year [13]. It is only non-edible biodiesel feedstock of Southeast Asia. Jatropha is a potential second generation biodiesel feedstock, though it still requires vigorous research and development for commercialization.

Unfortunately only Malaysia, Indonesia and Thailand are harvesting benefits of producing biodiesel. Other countries of SE Asia are far behind in this sector because of lack in infrastructure of biodiesel production and government support for growing biodiesel producing oilseed crops. A large number of selective literatures are reviewed in order to critically compare the feasibilities of this feedstock with other popular biodiesel feedstock like rapeseed, soy, cottonseed in different parameters like land use, fertilizer use, oxidation stability, engines chemical emission, oxidation stability. On selecting references, only highly rated journals with scientific references, Society of Automotive Engineer (SAE) technical notes are taken and some information's are gathered from reports from renowned organizations like Food and Agriculture Organization of the United Nations (FAO), International Energy Agency (IEA), European Biodiesel Board (EBB), European Committee for Standardization (CEN), National Institute of Standards and Technology (NIST) and Malaysian Palm Oil Board (MPOB), Malaysian Palm Oil Council (MPOC). The experimental results as well as reasoning behind these results are analyzed to find the jest. In most cases a clear cut comparison of results are not possible, as engines were different (single cylinder, multiple cylinder, different brands) also their operating conditions (speed, load, throttle position). The variation of oil specifications of same feedstock is another important fact for this variance in result.

Palm oil turns out as most prospective biodiesel feedstock. Because palm oil has a high yield factor, low fertilizer, water and pesticide consumption and palm oil methyl ester (POME) has low engine emissions, high oxidation stability apart from NO_x emissions which is higher. Jatropha is also promising as second generation biodiesel feedstock. But it requires more research to develop its properties to a satisfactory level for mass commercial usage.

2. Environmental impacts of biodiesel

A full life cycle assessment of biodiesel considering all the factors from production, processing, distribution, engine emission to calculate total well to wheel GHG effects, can judge biofuels effects on climate, whether it is a boon or bane? A flow diagram of life cycle analysis of conventional diesel and biodiesel is given in Fig. 1 to show the factors of GHG emissions in different stages of production, processing, transport and use.

Unfortunately, most of the papers put some percentage of GHG savings without mentioning what are the factors they have considered other than a clear comparison of petro diesel vs. biodiesel engine emission only. Grossly, 40–80% reduction of engine emissions is reported by most papers using biofuels, but very few discussed their basis of assessments. An attempt of measuring GHG emission has found 50% reduction while using palm oil in electricity production in comparison to coal based electricity production [14].

Following analogy published in IEA 2006 and FAO 2008 shown in Fig. 2 shows GHG savings is higher in palm based biodiesel in comparison to any other biodiesel feedstock excluding the effects of land use change.

Diesel engines are verdict of polluting environment by emitting CO_2, NO_x (nitric oxide, NO, and small amount of nitrogen dioxide, NO_2– collectively known as NO_x), particulate emissions, SO_2, unburnt hydrocarbons(HC) in significant level depending on engine load, speed and other operating parameters. Biodiesels are mostly plant based and in SE Asia it is palm oil based. Engine emission blue print is not as significant in environment of Southeast Asia as most of produced biodiesel is exported to EU and USA. Research and development in this region is focused mainly on emission performance of produced biodiesel for tightened emission standards for transport fuels worldwide.

2.1. By-products of transesterification

Transesterification or alcoholysis is the usual conversion process used to convert triglycerides of vegetable oil to fatty acid

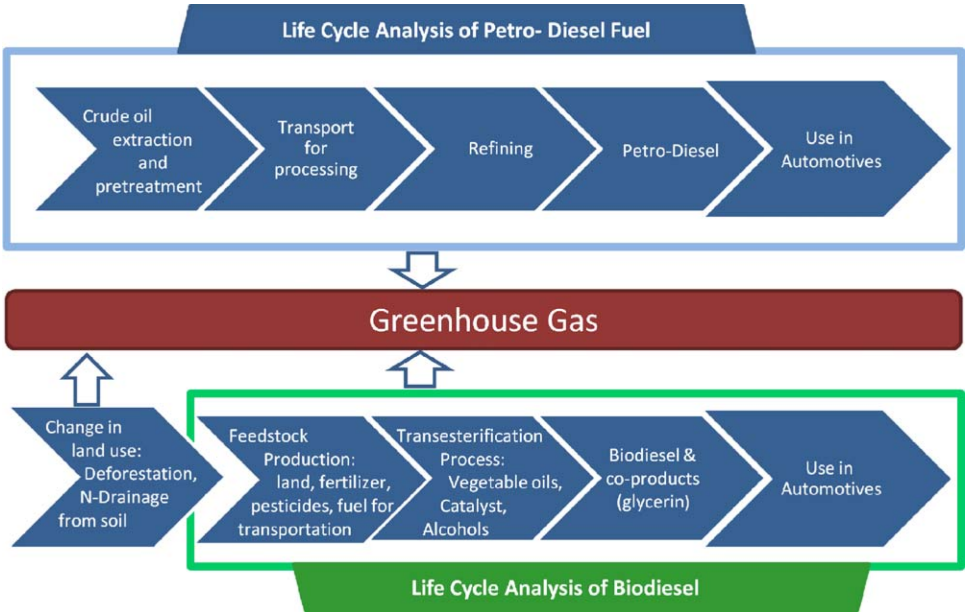


Fig. 1. Life cycle analysis of greenhouse gas balances of biodiesel and petro diesel.

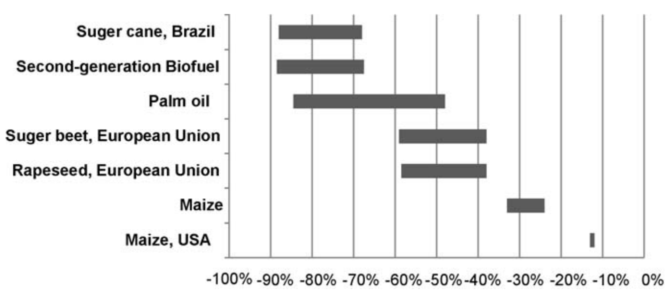


Fig. 2. Reduction of GHG emission of selected biofuels relative to fossil fuels [15].

methyl esters (FAME) by displacing alcohol from an ester by another alcohol [16]. For each triglyceride three monohydric alcohols reacts to produce (m)ethyl ester and glycerin (Fig. 3).

An access alcohol is used to move this reaction towards production side and catalysts are used to increase the reaction rate and yield of esters. Among alkali, acid and enzyme based catalysts, alkali based catalysts are more effective [5,17] and most widely used in industrial processes for its less corrosiveness to industrial equipments [18]. Fernando et al. (2007) suggested that total FAME content is more appropriate parameter for measuring the completeness of transesterification reaction rather than free glycerin contents of it [19]. In a stoichiometric material balance yield equation, 103 kg glycerol is produced from every 1 ton vegetable oil/fat [20]. This large amount of glycerol (also known as glycerin) produced as by-products of biodiesel can have adverse effect on environment if disposed on soil or water. This glycerin can be extracted for use in industrial purposes like pharmaceuticals, cosmetics, tobacco moisturizers, antifreeze, hydraulic fluids, propylene glycol. Effluents of palm oil mill are major source of water pollution. Wastewater generated from palm oil mill is namely sterilizer condensate, hydrocyclone waste, and separator sludge [21]. Oil palm mills generally generate numbers of biomass wastes. The amount of biomass produced by an oil palm tree, inclusive of the oil and lignocellulosic materials is on the average of 231.5 kg dry weight/year [22]. In most cases this huge amount of solid waste is burned in boiler and other heating purposes producing lots of smoke and polluting air.

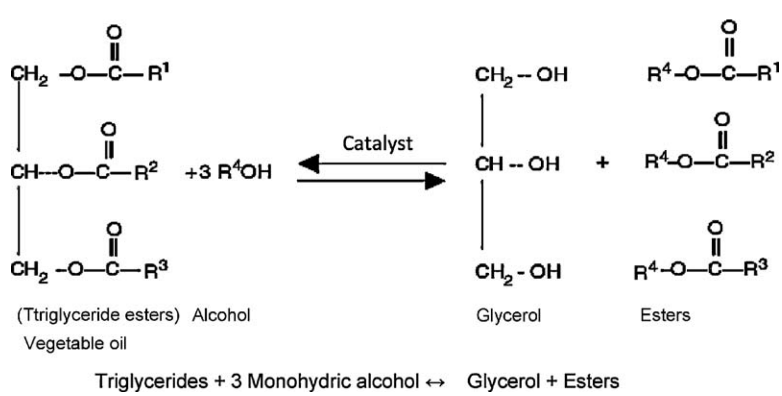


Fig. 3. Stoichiometric transesterification reaction.

Table 1
Oil producing crops [26].

Plant	Yield (seed) (lbs/acre)	Biodiesel (gal/acre)	Plant	Yield (seed) (lbs/acre)	Biodiesel (gal/acre)
Corn	7800	18	Safflower	1500	83
Oats	3600	23	Rice	6600	88
Cotton	1000	35	Sunflower	1200	100
Soybean	2000	48	Peanut	2800	113
Mustard	1400	61	Rapeseed	2000	127
Camelina	1500	62	Coconut[a]	3600	287
Crambe	1000	65	Palm Oil[a]	6251	635

[a] Yield given in lbs of oil/acre.

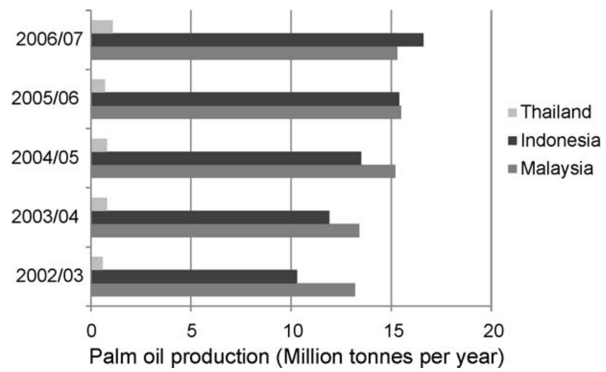


Fig. 4. Production of palm oil in Southeast Asia [27].

2.2. Plantation of oilseed crops

Biodiesel have a strong environmental effect in SE Asia caused mainly by the change in land use for cultivating vegetable oil plants (Palm, *J. curcas*). Increases in the size of plantations of palm tree can lead to the loss of rain forests, especially in SE Asia [23]. Government policies to promote biodiesel productions have boosted the supply side so far, rather than research and development as expected. Increased demand for palm oil has lured businessmen in acquiring paetlands of SE Asia by drastic logging and firing for palm oil plantation. Clearance of land for oil palm cultivation is one of the drivers for deforestation. Worlds 71% CO_2 emission occurs from oxidation in drained peatlands occurring in SE Asia which makes Indonesia in 3rd position in global CO_2 emission ranking [24]. Soil quality of this rainforest can be damaged irreversibly by death of microorganisms in sunlight, washing the soil minerals in heavy rainfall and flood. Depletion of rainforest as well as ensuing depletion of soil is major environmental concern of Indonesia [25].

Palm is among the highest yielding oilseed crop that can be easily comprehended from Table 1 [26] and growth of palm oil production is shown in Fig. 4 [27].

2.3. N-drainage from rainforest

For full life cycle emission analysis of GHG's, N_2O emission is needed to be considered with importance. N_2O is a by-product of fixed nitrogen application in plants as fertilizer and have 296 times global warming potential than an equal mass of CO_2 [28]. As a source for nitrogen, NO_x also plays a major role in strato-spheric ozone chemistry as well as global warming [29,30]. Crützen et al. [31] made an attempt to compare CO_2 saved by biofuel vs. N_2O released and came to a conclusion that agro-biofuels may cause more global warming by replacing fossil fuels. As a matter of fact, this threat is associated with excessive use of N-enriched fertilizers which is used all our crops and biofuel is produced from only 1% of world arable land. Because palm oil requires comparatively less N-fertilizers than other oilseed crops like rapeseed, maize. Moreover palm trees easily grow on poor soils, but without the need for extensive use of fertilizers and pesticides [23]. In comparison of r_N values shown in Table 2, this can be stated that palm is a minor contributor of N than rapeseed, maize and sugarcane. Wahid et al. [32] measured the r_N of palm 6.4 gN/kg dry matter which is lowest.

3. Engine emission

Engine temperature, load and speed affect emissions. Also ignition timing, fuel contents and fuel viscosity. Apart from using additives or customizing fuel properties by preheating or oxidizing, many aftertreatment devices like, particulate matter filter, exhaust gas recirculation (EGR) are used. This section is a brief review about the most prominent engine emissions when fueled with biodiesels.

3.1. Carbon dioxide (CO_2)

Many authors have claimed reduction of CO_2 emission whereas some authors reported excessive emission in SE Asia's from palm oil based diesel. Reijnders made some assumption based calculation and found emission of about 2.8–19.7 kg CO_2 equivalent per kg of palm oil [33]. But this calculation is strongly criticized [34] for not taking account of palm oil residues as biomass fuel extensively used in SE Asian palm oil mills [35–38]. Whereas non-edible Jatropha oil shows higher CO_2 as engine emission [39]. The CO_2 released into atmosphere by burning biodiesel is recycled by plants to grow oilseeds from which we get biodiesel by transesterification. So a significant reduction of CO_2 is expected and 78% net reduction of CO_2 is reported in 1998 biodiesel life cycle study conducted by US department of energy and US department of agriculture. Some other authors found insignificant change in CO_2 emission [40].

3.2. Nitrogen oxides (NO_x)

NO_x and particulate matter emission is most crucial for biodiesel. NO_x formation occurs in premixed combustion phase, whereas PM formation is influenced by the diffusion combustion phase. So an interactive trade-off in between PM and NO_x exists in diesel engine. Most of the authors have reported a rise in NO_x emission while operating diesel engines fueled by biodiesel. On the other hand, some claimed decrease of NO_x emission. Reviews have

Table 2
Relative warming derived from N_2O production against cooling by "saved fossil CO_2" by crops as a function of the actual nitrogen content $r_{N\,(actual)}$ [31].

Crop	r_N (gN/kg dry matter)	Relative warming (M_{eq}/M) (N-efficiency $e = 0.4$)	Type of fuel produced
Rapeseed	39	1.7	Bio-diesel
Maize	15	0.9–1.5	Bio-ethanol
Sugarcane	7.3	0.5–0.9	Bio-ethanol

Table 3
Research findings related to NO_x emission from biodiesel combustion.

NO_x emission	Palm oil	Jatropha oil	Other biodiesel feedstock
NO_x increase	Kalam and Masjuki [60]; (Preheated crude palm), Kalam and Masjuki [61]; (B20 with additive); Bari et al. [62]	Agarwal and Agarwal [39]; Pradeep and Sharma [54]; Senthil Kumar et al. [63]	Graboski and McCormick [20]; Murillo et al. [50]; (Cooking Oil), Jha et al. [64]; (Soyabean), Canakci and Sanli [65]; (Soyabean)
NO_x reduction	Kalam and Masjuki [60]; (Preheated crude palm with water emulsion); Kalam and Masjuki [66]; (B15 with corrosion inhibitor additive); Lin et al. [67]; Lin et al. [68]	Banapurmath et al. [13]; Senthil Kumar et al. [53]; Narayana Reddy and Ramesh [55]	Kalligeros et al. [69] (sunflower and olive oil), Altin et al. [70] (various vegetable oils)

Table 4
Suggested techniques to reduce NO_x.

Researchers	Suggestion to Reduce NO_x
Almeida [40]; Narayana Reddy and Ramesh [55]	Increase injection fuel pressure
Monyem and H. Van Gerpen [47]	Retard the injection timing
Johnson et al. [56]; Summers et al. [57]; Uyehara [58]	Use EGR after treatment
Pradeep and Sharma [54]	Hot EGR for Jatropha feedstock
Keskin et al. [59]	Use of Mn and Ni based additives can bring down NO emission to 24.6% in tall oil
Szybist et al. [51]	Use cetane number improver additives

tried to investigate reasons of NO_x emission in diesel engines and ended up in paradoxical remarks.

NO is produced more in post-flame gases than in flame-front. Mixture which burns early in the combustion process is especially important since it is compressed to a higher temperature, increasing the NO formation rate, as combustion processed and cylinder pressure increases [41]. Most of the papers indicate injection advanced for use of biodiesel, due to its low compressibility (higher bulk modulus) [42–44] and faster propagation towards injector for high sound velocity. Also the high viscosity stimulates high in line pressure by reducing leakage and resulting high temperature peaks and NO formation rates [45–50]. This reasoning is strongly opposed [51] as NO_x formation begins well after combustion [52]. They pointed lower cetane number as main culprit for NO_x emission. But NO_x formation seems more like a thermal phenomenon as supported by most authors. Jatropha methyl ester emits lower NO_x than diesel due to low cylinder peak pressure and lower heat release rate [39,53,54]. Significant NO emission reduction is achieved by increasing injection pressure as well as advancing injection timing using Jatropha in a single cylinder direct injection diesel engine [55]. Tables 3 and 4 shows a quick summary of the researcher's findings about NO_x emission from diesel engines when run of different biodiesel feedstock and their suggestions to compensate it.

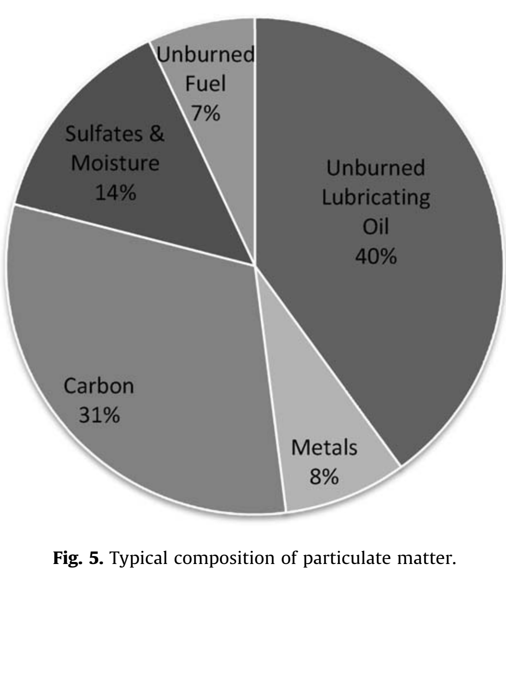


Fig. 5. Typical composition of particulate matter.

3.3. Particulate matter (PM)

Particulate matter consists of elemental carbon (≈31%), sulfates and moisture (≈14%), unburnt fuel (≈7%), unburnt lubricating oil (≈40%) and remaining may be metals and others substances [4]. Fuel standards are heavily coming against PM emission due to its infectivity and asthma aggravation. Near zero sulfur content of biodiesel prevents sulfate formation and HC absorption on soot surface [60,71]. Significant reduction of PM and soot in observed in most of the experiments when diesel engines are fueled with biodiesels, irrespective of different feedstock. Most authors given the reason to higher oxygen content in biodiesels than diesel which promotes further oxidation of soot particles [20,47–49]. But raw Jatropha oil and Jatropha methyl ester both emit more smoke and PM [63]. Moreover, the injection advance caused by use of biodiesel also exposes the fuel mix longer time in high temperature atmosphere along with the higher cetane number of biodiesel can lead to a less PM emission (Fig. 5).

3.4. Unburnt hydrocarbon (HC) and carbon monoxide (CO)

HC and CO are products of incomplete combustions. More precisely speaking, during diffusion in combustion and flame quenching these emission occurs. Other causes are rich fuel air ratio with insufficient oxygen, incomplete combustion of lube oil and hydrocarbons absorbed by oil film and admit in exhaust by misfire [60]. HC and CO emission is higher in full load other than partial loads while using palm and other vegetable oil methyl esters as fuel [72]; this is due to the increase of incomplete combustion at full load caused by scarcity of oxygen [40]. Most of the authors found significant reduction of HC and CO from different types of biodiesels in various types of engines, viz. of Nwafor et al., [74] used rapeseed oil, Kalligeros et al., [69] tested sunflower and olive oil, Scholl and Sorenson [73] experimented with soybean oil. Similar result is reported [47,60,61,66] by using palm oil methyl ester with some exceptions [72]. But Jatropha methyl ester emits more HC and CO compared to conventional diesel [13,39,53,63]. Preheating Jatropha oil and using in lower proportion blends with diesel have reduced emission, though not lower than conventional diesel [39]. But Narayana Reddy and Ramesh, [55], found less HC and CO emission by increasing injection pressure and advancing injection timing while using Jatropha as fuel in diesel engine. Higher oxygen content of vegetable oils leads to complete and cleaner combustion as well as higher cetane number of biodiesels

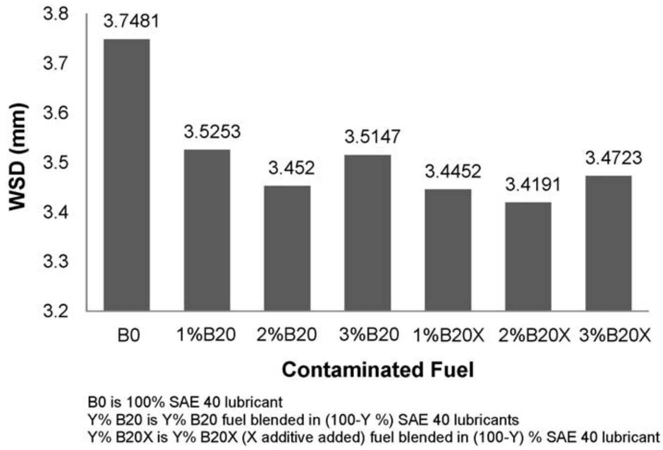


Fig. 6. Wear scar diameter (WSD) measured by four ball method with various contaminated fuels at constant load of 50 Nm [61].

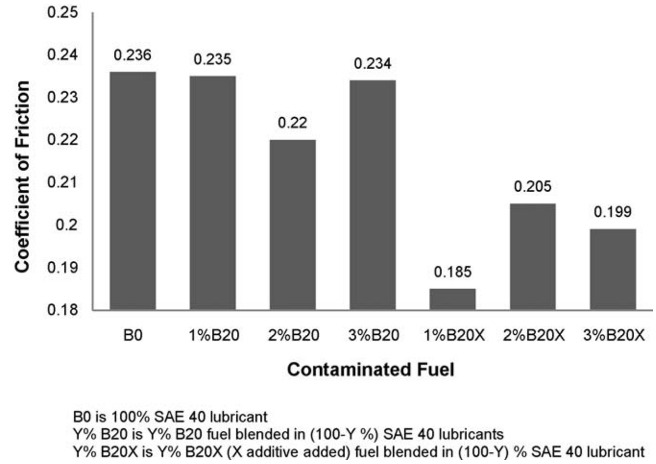


Fig. 7. Coefficient of friction for various contaminated fuel's lubricants at constant load of 50 Nm [61].

reduces combustion delay and probability of fuel-rich zones formation which are prone to HC and CO emissions [49].

4. Engine compatibility studies

Some critical problems of straight vegetable oils in diesel engine are cold weather starting, plugging and gumming of filters, engine knocking, coking of injectors on piston and head of engines, carbon deposits on piston and head of engines, excessive engine wear, poor atomization, piston ring sticking, fuel pump failure of engine lubricating oil due to polymerization [4–6,75–79]. All this problems are caused by some common reasons like high viscosity, very low cetane number, and blowby of crankcase. By transesterification vegetable oils viscosity can be reduced [75,78,80] and some author [41,62] prescribes preheating of oil, others [59,61,81–84] uses additives to tackle such problems and make biodiesel more adaptable in diesel engine without any engine modification.

4.1. Wear

Wear is an important characteristic to validate engine compatibility of a fuel as it relates to material loss from engine parts and energy consumption. Many authors have attempted to compare wear effect of biodiesel in different methods. Using palm oil methyl ester as feedstock blend some authors found significantly low wear of some engine material [61,85–90]. But pure palm shows higher friction and wear effect in diesel engines in comparison to petro diesel [86,88]. Fuel dilution as well as change in viscosity is lesser in biodiesel fouled system compared to diesel fueled system [4]. Due to oxidative characteristics biodiesel causes more corrosion and wear to engine parts especially where fuel comes in contact during operations. In response to this effect [61] used anti-wear additives and found significant reduction of wear properties as shown in Figs. 6 and 7.

4.2. Corrosion

Corrosion also plays little part in engine part degradation due to acidic nature of palm oil diesel. The water content of POD can convert some esters into fatty acids by reverse reaction shown in Fig. 2 under favorable conditions and this acid causes corrosive wear to engine parts like piston ring, piston liner, etc. Very few investigations are found on this issue. Moreover vegetable based palm oil contains palmitic and free fatty acids in its composition which reduces wear when palm is contaminated in lube oil [86]. Long duration static immersion test of piston liner and piston metal is conducted by [91] found slightly corrosive nature of *J. curcas* biodiesel which could be caused by presence of linoleic acid in oil (19–41%). Desired anti-corrosive properties are successfully introduced in palm biodiesel blends by using anti-corrosive additives [66].

5. Blending role's and oxidative stability improvement

Oxidation stability is vital for longer storage period without degradation of quality, standardization. Biodiesel causes higher oxidation when comes in contact with lube oil and causes slightly higher viscosity [4] which could lead to low break specific fuel consumption. The fatty acids in the palmitic lubricant might cause high chemical reaction on the metal surface and hence oxidize the lube oil [89]. Crude palm oil methyl esters are found to exhibit better oxidative stability (rancimat induction period >25 h) than distilled palm oil methyl esters (about 3.5 h) [92]. Formation of resinous products because of oil oxidation, evaporation of lighter fractions, depletion of anti-wear additives, and contamination by insoluble tend to increase the viscosity while fuel dilution and shearing of viscosity index improvers tends to bring down its viscosity [4]. Sarin et al., [93] carried out oxidation stability test by EN 14112/IS 15602 test method with different feedstock and found high oxidation stability (13.37 h) of POME even in high temperature due to its large fraction of saturated fatty acid (43.4%). Though Jatropha shows lower stability (3.23 h) which is higher than sunflower (1.73 h). To improve stability anti-oxidant dosing is quite effective nevertheless mixing POME in higher proportion with Jatropha biodiesel also attains higher stability than only Jatropha biodiesel [93] (Fig. 8).

6. Biodiesel standardization

Table 5 represents a summary of biodiesel standards under practice around the world along with corresponding properties of palm methyl ester and Jatropha methyl ester.

7. Future challenges of biodiesel

There are many challenges for SE Asian counties to establish biodiesel as a substitute for conventional petro diesel. So far biodiesel is commercialized by government and enjoyed high subsidies. Main hurdle in penetrating the market is reducing the high production cost of biodiesel to make it competitive with

Table 5
Physicochemical properties of biodiesel.

Property (units)	Malaysia (Cheah et al. [94])	Indonesia (Indonesian National Standardization Agency [95])	Thailand E 14214	USA ASTM D6751 (NIST [96])	EU E 14214 (NIST [96])	Brazil ANP 42 (NIST [96])	Jatropha methyl ester (Sarin et al. [93])	Palm oil methyl ester (Sarin et al., [93])
Flash point (°C)	182 min	100 min	120 min	130 min	120 min	100 min	163	135
Viscosity at 40 °C (cSt)	4.415	2.3–6.0	3.5–5	1.9–6	3.5–5	–	4.4	4.5
Sulfated ash (% mass)	0.01 max.	0.02 max.	0.02 max.	0.02 max.	0.02 max.	0.02 max.	0.002	0.002
Sulfur (% mass)	0.001 min	0.001 min	0.001 min	0.001 min	0.001 min	–	0.004	0.003
Cloud point (°C)	15.2	max. 18	–	–	–	–	4	16
Copper corrosion (3 h, 50 °C)	Class 1	Class 3	1	Class 3	Class 1	Class 1	1	1
Cetane number	–	51 min	51 min	47 min	51 min	–	57.1	54.6
Water and sediment (vol.%)	0.05 max.	0.05 max.	–	0.05 max.	–	0.05 max.	0.05	0.01
CCR 100% (mass%)	–	–	max. 0.3	0.05 max.	–	0.1 max.	<0.01	<0.01
Neutralization value (mg, KOH/gm)	–	–	–	0.05	0.05	0.08	0.48	0.24
Free glycerin (mass%)	max. 0.01	max. 0.02	max. 0.02	max. 0.02	max. 0.02	max. 0.02	0.01	0.01
Total glycerin (mass%)	max. 0.01	max. 0.24	max. 0.25	max. 0.24	max. 0.25	0.38	0.02	0.01
Phosphorus (mass%)	–	max. 10 ppm (mg/kg)	max. 0.001	max. 0.001	max. 0.001	–	max. 0.001	max. 0.001
Distillation temperature	–	<360 °C	–	< 360 °C	–	<360 °C	–	–
Oxidation stability (h)	–	–	6	3	6	6	3.23	13.37

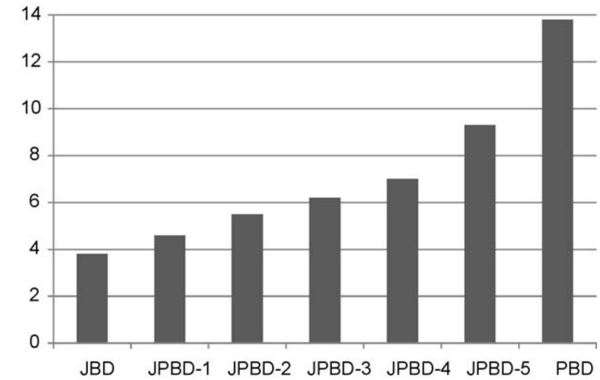


Fig. 8. Oxidation stability of Jatropha–palm biodiesel blend (JPBD).

petroleum fuels. Major factor determining biodiesels price is its feedstock price [20]. To reduce cost, modification of a high yielding, low cost transesterification process. SE Asian countries have a strong agricultural sector with low manpower cost, tropical environment and high yielding oilseed crops. From this, smallholder farmers will be benefitted by generating employment and increasing rural incomes, but the scope of those benefits is likely to remain limited with current technologies [97]. Technological advancement through continuous research and development is another challenge for SE Asian countries.

Before the prologue of transesterification process vegetable oils are been used and experimented by many researchers. Most authors reported heavy carbon deposition, filter plugging, injector coking, ring sticking, fuel system failure, cold weather starting, gum and wax formation, and lubricating oil contamination, etc. while using vegetable oils as alternative fuel. These problems are dominant when 100% vegetable oil is used as fuel in diesel engines. Some common reasons are pointed by most researchers as high viscosity, low volatility, impurity, free fatty acid, polymerization, free water, etc.

The challenge of biodiesel is not only in short term operation in diesel engine, but is long term engine operation and reduction of its high production cost [11]. Researchers have measured biodiesel performance in engine and found some problems caused by biodiesel. Most of these problems are eminent and caused catastrophic engine failure when straight vegetable oil is used. These problems are summarized in Table 6. But these problems still exist in automotive uses in marginal level, though auto-manufacturers are considering this as main reason for not certifying biodiesel as fuel in their vehicles. Overcoming this problems are challenges for engine manufacturers and researchers in next decade. This will also effect to achieve the set targets by different countries to replace fossil fuels in certain extend by renewable sources. These targets are summarized in Table 7.

8. Sustainable energy policy

Form the policies of Southeast Asian countries it can be easily comprehended that, they are mainly focused on export rather than utilization in their own countries and less concern about environment. All these countries pay heavy subsidies on petroleum transport fuel which are imported. On the other hand, to commercialize self-produced biofuel they need to pay more subsidies as biofuel price is still a bit higher. Bridging the gap by subsidies became infeasible due to the low petroleum prices (USD 45.71/barrel crude oil in March 11, 2009). Malaysian government have stopped the Envo Diesel (5% Palm Methyl Ester and 95% Diesel) project as it failed to market it at 2008 as planned

Table 6
Problem and causes in vegetable oil run diesel engines.

Problems	Causes of problem	Researchers
1. Carbon deposits on piston, piston rings, valves, engine head and injector tips	High viscosity of vegetable oil, incomplete combustion, poor combustion in partial load	Agarwal [4]; Labeckas and Stasys [76]; Ramadhas et. al. [75]; Kalam and Masjuki, [60]; Ma and Hanna [5]; Nag et. al. [98]; Schlick [99]; Harwood [6]; Pestes and Stanisalo [77]; Engler et al. [100]
2. Filter plugging, injector coking, nozzle blocking	Polymerization products, impurities, free glycerin, FAME process chemicals (K, Na, detergents, etc.)	Labeckas and Slavinskas [76]; Jones et. al. [101]; FIE manufacturer [102]; Ryan et al. [103]; Peterson et al. [104]; Pryor et al. [105]; Bruwer et al. [106]; Van der Walt and Hugo [107]
3. Failure of engine lubricating oil	Collection of polyunsaturated vegetable oil, blow-by in crankcase to the point where polymerization	Agarwal [4]; Ma and Hanna [5]; Mittelbach [108]; Perkins et al. [109]; Reid et al., [110]; Schlautman et al. [111]; Harwood [6]; Engler et al. [100]; Hofman et al. [112]
4. Cold weather starting	High viscosity, low cetane and low flash point of vegetable oils	Agarwal [4]; Prateepchaikul and Apichato [113]; Perkins et al. [109]; Baranescu and Lusco [114]; Sims et al. [115]
5. Heavy gum and wax formation, deposition on piston, piston rings, injectors and cylinder wall	High viscosity, oxidation	Silvico et al. [119]; Zieiwski and Goettler [116]; Tahir et al. [117]; Peterson et al. [118]; Hofman et al. [112]
6. Corrosion of high pressure injecting pump, injectors, injector nozzles, supply or feed pumps, high pressure pipes	Free water, free FAME, corrosive acids (formic & acetic), free methanol, NaOH or KOH particles in fuel, high viscosity at low temperature, iodine value, total acid number, etc.	Brink et al. [120]
7. Fuel delivery problems, poor nozzle spray atomization	Higher viscosity at low temperature	FIE manufacturers [102]; Allsup [121]
8. Elastomer like nitrile rubber softening, swelling, hardening, cracking	Free methanol, free water in mixture	Bosch [122]

Table 7
Short summery of worldwide biofuel targets [15,23,123–125].

Country	Official biofuel targets
Brazil	40% rise in ethanol production, 2005–2010; Mandatory blend of 20–25% anhydrous ethanol with petrol; minimum blending of 3% biodiesel to diesel by July 2008 and 5% (B5) by end of 2010
Canada	5% renewable content in petrol by 2010 and 2% renewable content in diesel fuel by 2012
European Union	10% in 2020 (biofuels); target set by European Commission in January, 2008
UK	5% by 2020 (biofuels, by energy content)
Indonesia	2.5 vol.% of biodiesel blend in diesel and 3% ethanol blend in gasoline by 2010
Malaysia	EnvoDiesel in all fuel stations and industrial sectors from 2008 (but it failed). Currently its more focused in quality biodiesel export rather than utilization inside country
Thailand	5% and 10% replacement of diesel respectively in 2011 and 2012

in "The National Biofuel Policy" surfaced in 21 March, 2006 [122]. Moreover, Germany has curtailed their subsidies on biofuels. As a result many fuel stations in Germany and palm industries in Malaysia suspended operations last year. But in January, 2009, palm diesel production has accelerated in Malaysia along with Indonesia as palm oil price gone down 75% with respect to January 2008 [123]. The Government of Indonesia established its first national policy on biofuels in 2006 by setting a target of replacing 10% transport fuel by biofuel by 2010. National oil company Pertamina started selling B5 biodiesel blends commercially but suffered serious financial losses due to high feedstock price of biofuel. To compensate losses the blend ration is lowered to 1% now. This phenomena have plunged the Indonesian government to subside the target to 2.5% diesel excision by biodiesel and 3% gasoline by ethanol in 2010 [124]. Thailand has progressed well after setting a target in January, 2005 to replace 10% diesel by biodiesel by 2012. About 800 gas stations were selling B5 blends in 2007. A steady progress of Thailand and Indonesia in this sector is due to availability of many different type of feedstock. Thailand's main biodiesel feedstock is palm but it has coconut oil, Jatropha oil, waste cooking oil and bioethanol producing plants based on molasses, cassava and sugarcane. Indonesian bioethanol plans uses sugarcane and cassava as feedstock. Whereas Malaysia's biofuel production is grossly focused only in palm diesel, this makes it more vulnerable to volatile petroleum and palm oil (food grade) prices. Nevertheless, palm oil's versatile applications, ranging from food products to biodiesel, have made it the most sought after vegetable oil in the world. A subsequent growth of Jatropha oil production could have leaded a sustainable energy security through biodiesel [9].

9. Conclusion

From the overall review this can be assessed that Southeast Asian countries possess a huge prospect for biodiesel production. Because of high yield factor of palm in its tropical climate, less requirement of fertile land, fertilizer and pesticides made this feedstock, environment friendly low carbon fuel. On the other hand, engine emissions are significantly low in POME except NO_x emission. Moreover, oxidation stability of palm is more than that of Jatropha and other biodiesel feedstock. This is a reason of staggering demand of palm based biodiesel in international market. This surge consequently makes the outlook for conservation of the rainforests SE Asia bleak. Firing and logging of rainforest should be strictly oppressed for the sake of sustainable feedstock production by government policy. Meanwhile keeping a steady supply of feedstock of biodiesel and edible oils simultaneously is another challenge for ensuring food and energy security. Jatropha

being non-edible oil and easily grown in non-cropped marginal lands and wastelands [126], stands as a future second generation biodiesel of this region.

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